STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
Pullman, Washington

Division of Plant Pathology

Studies on the Control and Other Aspects of Bunt of Wheat

by

C. S. Holton and F. D. Heald

Bulletin No. 339

September, 1936

All bulletins of this Station are sent free to citizens of the State on application to the Director

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INTRODUCTION

The control of bunt of wheat still continues to be a problem in the Pacific Northwest. Fungicides such as formaldehyde and copper carbonate have been very extensively used for seed treatment. The former is now recommended for treatment of spring wheat only while the latter may be used for either spring or fall seedings. Ceresan and the New Improved Ceresan are of more recent introduction. The principal incentive for further tests with seed disinfection is to find either effective fungicides that are cheaper than those in general use or that will be more effective in the prevention of smut from soil contamination. In these relations copper arsenite and basic copper sulphate seemed to offer some promise. Further tests have been made to determine the relation of certain practices to the effectiveness of the standard dust disinfectants. Some other control practices which have not been in general use have also been tested.

Brief data are presented on physiologic strains of wheat varieties in relation to smut infection, a feature which has been generally overlooked. The present status of physiologic races of bunt species, varietal resistance and the effect of bunt on winter hardiness under Washington conditions is presented.

TESTS WITH FUNGICIDES

Copper Arsenite for Soil-borne Smut

Many of the fungicides that have been tested are very effective in the control of smut from seed contamination, but have only a slightly beneficial effect in reducing the percentage of smut when seed is planted in a smut-contaminated soil. The desirable fungicide for fall-seeded wheat in the Palouse country is one which will either prevent bunt from soil-borne spores or reduce the amount to a safe minimum. Since very promising results were reported by Petit (15) for copper arsenite dust, it seemed advisable to test this material under Palouse conditions.

Artificially contaminated ground was prepared by spraying the soil with a light and a heavier water-suspension of spores. Untreated and copper-carbonate-dusted Hybrid 128 were used for comparison with the same variety dusted with copper arsenite powder at the rate of two and four ounces per bushel with the results shown in Table 1.

Table 1. Comparison of Effectiveness of Copper Carbonate Dust and Copper Arsenite Dust in Prevention of Bunt from Soil-borne Spores

Hybrid 128—Seeded, Fall, 1933

Treatment	Light contamination — Per cent of smut heads 4 replications			Heavier contamination — Per cent of smut heads 4 replications		
	Max.	Min.	Ave.	Max.	Min.	Ave.
Untreated	22.0	7.3	13.2	25.4	18.4	22.2
Copper carbonate 50%—2 ozs.	8.6	1.7	4.4	15.5	9.6	12.5
Copper arsenite 2 ozs.	8.5	2.7	4.6	14.0	8.9	11.1
4 ozs.	8.9	2.9	5.1	14.2	6.4	8.7

In this test copper carbonate dust and copper arsenite dust at the rate of two ounces per bushel were about equal in effectiveness with the elimination of about one half of the smut as contrasted with the untreated seed, while an increase of copper arsenite to four ounces per bushel gave but little added protection.

Basic Copper Sulphate

The use of fungicidal dusts for the treatment of wheat for bunt or stinking smut has very largely replaced the various liquid disinfectants. Any new dust to justify its adoption must compete with copper carbonate and the New Improved Ceresan in cost and general effectiveness. The tests which have been made with basic copper sulphate, (Basul) a fungicide manufactured by the Sherwin Williams Co., Cleveland, Ohio, indicate that it has all of the advantages claimed for copper carbonate dust (9) and according to present quotations will be available at a lower cost per pound.

Effect on Viability of Seed. Two standard varieties were used in determining the effect of basic copper sulphate on the germination of the treated seed. Germination tests of treated and untreated seed at monthly intervals for one year were made in the greenhouse in representative field soil in flats using 200 seeds of each variety with the results shown in Table 2. These tests show in general a better germination of the treated grain than of the untreated, and no reduction in germination one year after treatment, but rather a slight improvement in viability at the end of the test as compared with the viability at the beginning.

Table 2. Percentage of Germination at Monthly Intervals of Wheat Seed Held in Storage after Treatment with Basic Copper Sulphate, 2 ozs. per Bushel

Date of germination test 200 seeds	Albit		Federation	
	Untreated	Treated	Untreated	Treated
3-17-34	84.8	89.2	76.04	87.7
4-14-34	87.7	94.6	83.85	85.4
5-19-34	93.6	97.7	87.7	87.3
6-19-34	94.2	96.8	92.6	93.6
7-19-34	81.02	92.59	67.08	87.5
8-20-34	84.7	88.79	76.84	86.57
9-22-34	75.9	81.0	77.8	82.3
10-10-34	85.2	87.9	64.4	72.7
11-21-34	89.06	94.2	78.5	83.6
12-21-34	89.8	93.5	85.7	91.7
1-27-35	86.1	90.8	79.6	85.6
2-27-35	86.6	94.4	81.5	91.7

Effectiveness in Smut Prevention. Smutted seed of two spring wheat varieties, Federation and Marquis, was used for determining the efficacy of basic copper sulphate in bunt control. Three seed lots of each variety were inoculated with light, medium, and heavy spore loads, and basic copper sulphate applied at the rate of two ounces per bushel gave complete freedom from smut in the crops grown from samples carrying the light spore loads (Table 3). Marquis, the more resistant of the two varieties, showed no smut in the lot carrying the medium spore load and only traces in the planting of heavily smutted seed, while in Federation the lots carrying medium and heavy spore loads showed a very light infection. It should be pointed out that the amount of smut used for the medium and heavy spore loads was sufficient to produce a very conspicuous blackening of the seed and that such heavily smutted seed is not recommended for planting. Complete protection was obtained in the lots carrying the light spore load, which was still sufficient to cause a visible blackening of the seed.

Since it has been shown by the germination tests that seed treated with basic copper sulphate has an improved viability after being stored for one year, it was important to determine the effect of holding treated wheat on the effectiveness of the protection against bunt. The results (Table 4) show that seed treated in March, 1934 and held in storage until April, 1935 when it was planted, was as

Table 3. Effectiveness of Treatment of Seed with Basic Copper Sulphate Dust in Control of Bunt, Pullman, Wn., Spring, 1934

Treatment	Spore load in grams per 120 of seed	Per cents of smut in 4 plots of Federation			Per cents of smut in 4 plots of Marquis		
		Max.	Min.	Ave.	Max.	Min.	Ave.
Untreated check	0.1	23.3	9.4	17.5	5.4	1.4	3.0
	0.4	41.7	38.2	39.9	11.9	10.5	11.3
	1.5	50.5	43	44.4	34.4	32.6	33.7
Basic copper sulphate 2 ozs. per bu.	0.1	0	0	0	0	0	0
	0.4	0.1	0	0.02	0	0	0
	1.5	0.5	0	0.1	0.1	0	0.1

effectively protected from infection as if it had been treated immediately before seeding. The results obtained in trials recorded above indicate that wheat may be treated and stored for an extended period before seeding without impairing either the germination or the effectiveness of the protection against bunt.

Table 4. Effect of Holding Wheat Treated with Basic Copper Sulphate Dust on the Effectiveness of the Control

Seed Smutted and Treated, March, 1934; Seeded at Pullman, April, 1935

Variety	Treatment	Per cent of smut heads		
		Ave. of 5 replications	Max.	Min.
Marquis	Inoculated and untreated	34.08	42.75	22.81
Marquis	Inoculated and treated 2 ozs. per bu.	0.3	0.89	0.0
Federation	Inoculated and untreated	32.73	59.84	16.42
Federation	Inoculated and treated 2 ozs. per bu.	0.15	0.38	0.0

Other Fungicides

The Effect of the Lapse of Time between Treating and Seeding on the Effectiveness of Certain Dusts. One of the advantages of the dust disinfectants for bunt control is that they may be applied some time prior to planting. Tests were made to determine whether

the effectiveness of certain dusts depends upon the length of time which elapses between application of the dust and planting the seed.

Hybrid 128 was used for a winter variety and Federation for spring planting. For each periodic test a lot of wheat was heavily smutted (0.5 gram of smut to 100 grams of seed) with spores from freshly ground smut balls and divided into four lots: (1) the untreated check; (2) treated with 20 per cent copper carbonate; (3) treated with 50 per cent copper carbonate; and (4) treated with Ceresan, all at the rate of three ounces per bushel. The four lots of Federation included treatments made nine, six, three and lastly one-fifth month previous to seeding on March 20, 1934. The test with Hybrid 128 included four lots representing treatments made three months two months, one month, and one-fifth month previous to seeding on October 6, 1933. All lots were planted in 7-foot rows, replicated four times. The results are summarized in Table 5.

In the spring seeding with Federation, 50 per cent copper carbonate gave the best control and was equally as effective when applied

Table 5. The Effect of the Lapse of Time between Treating and Seeding on the Effectiveness of Certain Dusts in the Control of Bunt

Federation—Planted 3-20-34

Treatment		Time in months between treatment and planting and the per cents of smut obtained			
Amount per bu.	Fungicide	9	6	3	3/4
None	Check	72.5	72.5	67.5	84
3 ozs.	Copper carbonate dust, 20 per cent	2.4	3.0	2.6	1.8
3 ozs.	Copper carbonate dust, 50 per cent	0.9	0.5	0.3	0.7
3 ozs.	Ceresan	14.8	13.2	11.4	3.0

Hybrid 128—Planted 10-6-33

		3	2	1	1/5
None	Check	92.5[a]	82.2	88.0	87.0
3 ozs.	Copper carbonate dust, 20 per cent	22.5	14.5	16.5	12.0
3 ozs.	Copper carbonate dust, 50 per cent	8.2	6.7	7.0	7.5
3 ozs.	Ceresan	20.2	19.0	15.2	25.2

[a] The per cents recorded are the averages of four replications.

several months in advance of seeding as when applied three weeks in advance. Likewise 20 per cent copper carbonate was about equally effective on all dates of application. Ceresan, however, showed a gradual increase in effectiveness as the length of time between application and seeding decreased (Table 5). These results with copper carbonate are contrary to those obtained by Flor (3).

In the fall seeding with Hybrid 128 the 50 per cent copper carbonate gave the best control and was about equally effective for the lots treated for the different lengths of time previous to seeding. With the 20 per cent copper carbonate the best control was given by the recently treated seed, although the difference was not very marked with the exception of the lot treated three months before seeding. The results with Ceresan permit no definite conclusion as to the effect of holding treated seed before planting since the most recently treated seed gave more smut than the seed treated three months before seeding.

In further explanation of the results with the fall plantings of Hybrid 128 it should be pointed out that several factors were probably operating to produce fairly high per cents of smut in all of the treatments. The date of seeding, October 6, was a time when about maximum soil contamination may be expected. At this time the soil moisture and the soil temperature were also favorable for high infection. These results are in agreement with general farm experiences that fall-seeded wheat of very susceptible varieties may frequently show much smut even though treated with standard disinfectants that are entirely satisfactory for spring plantings.

Table 6. Effect of Date of Seeding on the Effectiveness of Certain Dusts in the Control of Bunt

Hybrid 128, Fall, 1931

Treatment	Dates of seeding and per cents of smut					
	9-5	9-15	9-25	10-5	10-15	10-25
Check A	10.2	53.1	84.6	79.4	95.9	73.0
Check B	11.6	67.5	78.3	62.6	43.7	78.0
$CuCO_3$—20%	1.5	2.4	4.2	7.3	12.1	17.1
$CuCO_3$—20%	0.0	7.4	8.0	6.6	10.8	12.6
$CuCO_3$—50%	0.3	3.1	1.4	3.6	7.7	14.3
$CuCO_3$—50%	0.0	7.0	3.4	4.1	5.1	27.2
Ceresan	0.7	1.8	2.6	6.7	15.8	20.4
Ceresan	0.4	6.2	4.0	7.6	27.6	24.1

Heavily smutted Hybrid 128 was treated just previous to the first date of seeding: one lot with 20 per cent copper carbonate; a second with 50 per cent copper carbonate; and the third with Ceresan, all at the rate of three ounces per bushel. Plantings made at intervals of 10 days from September 5 to October 25 (Table 6) gave results similar to those reported by Flor (3). In general, the per cent of smut in the untreated rows varied with the date of planting, the earlier and the last dates showing less smut than the three intervening dates. The 50 per cent copper carbonate was more effective in controlling bunt than the 20 per cent grade and both of these were more effective than Ceresan. The effectiveness of all three of these dusts decreased as the percentage of bunt in the untreated rows increased except in the case of the last date of seeding. In this case the percentages of bunt in the untreated rows were lower than in the untreated rows of the previous date and the dusts were less effective on the last date. Consequently, these results indicate either that in the treatment of winter wheat for bunt control the effectiveness of copper carbonate, as well as Ceresan decreases as the lapse of time between application and planting increases, or that the soil temperature and moisture complex and the soil contamination were such as to reduce the effectiveness of the fungicides.

Comparative Effectiveness of Ceresan and New Improved Ceresan. The New Improved Ceresan was introduced to replace the dust disinfectant sold under the name of Ceresan for seed treatment for the prevention of certain diseases of small grain crops. A test was conducted to determine the comparative effectiveness of these dusts in the control of bunt.

Seed of Hybrid 128 was smutted (0.5 gram of smut to 100 grams of seed) and divided into three lots. One was treated with New Improved Ceresan at the rates of one-half and two ounces to the bushel; another with Ceresan at the rate of two ounces to the bushel; and the other was left untreated. The results from each lot planted in rod-rows, and replicated four times are summarized in Table 7. There was an average of 85 per cent of bunt in the check rows; averages of 3.1 and 0.02 per cent in the rows planted with seed that was treated with New Improved Ceresan at the rate of one-half and two ounces to the bushel, respectively; and an average of two per cent bunt in the rows planted with seed that was treated with Ceresan at the rate of two ounces to the bushel. According to these results, then, it is apparent that the New Improved Ceresan applied at the rate of one-half ounce to the bushel is nearly as effective as Ceresan at two ounces to the bushel in controlling bunt of wheat. At two ounces to the bushel the New Ceresan was more effective than the Ceresan but it caused a slight reduction in stand and plant vigor, whereas the one-half ounce rate gave no indication of seed injury. Further-

Table 7. **Comparative Effectiveness of Ceresan and New Improved Ceresan in the Control of Bunt**

Heavily Smutted Hybrid 128, Seeded Fall, 1933, Pullman.

Treatment	Per cent of smut heads 4 replications		
	Max.	Min.	Ave.
Ceresan	5.3	0.7	2.0
2 ozs. per bu.			
New Improved Ceresan			
½ oz. per bu.	3.9	0.9	3.1
2 ozs. per bu.	0.1	0.0	0.02
Check, untreated	95.0	70.0	85.0

more, the New Improved Cersean, used at the recommended rate of one-half ounce to the bushel, is more economical than Ceresan. The directions for treating the seed, which are printed on the commercial label, should be closely followed in order to obtain the best results.

Relation of Physiologic Races to Effectiveness of Copper Carbonate (50 per cent) in Prevention of Bunt. Although copper carbonate dust has long been recommended for the prevention of bunt there have been occasional reports of unsatisfactory results with this seed treatment. In seeking an explanation for reported unfavorable results it has been suggested that the bunt caused by some physiologic races of *Tilletia tritici* and *T. levis* is more difficult to control than that caused by other races

Tests with several varieties of wheat have been made to determine whether copper carbonate is equally effective in controlling bunt caused by different physiologic races of *Tilletia tritici* and *T. levis.* The lots were smutted at the rate of 0.5 gram of spores to 100 grams of seed, using six physiologic races of *T. tritici* and four of *T. levis* on Hybrid 128; two races of *T tritici* on both Hohenheimer and Ridit; and one race of *T. levis* on Ridit. All lots were then treated with copper carbonate dust at the rate of three ounces per bushel, and planted in duplicate rod rows at the rate of 10 grams of seed to the row. The results are summarized in Table 8.

In general, the data seem to indicate that the copper carbonate was less effective in preventing the bunt of the *Tilletia tritici* races than of the *T. levis* races. The Hohenheimer races, 7 and 7a of T. *tritici* on Hybrid 128 were less effectively controlled than the other races. This appears to be significant in view of the fact that three

Table 8. Effectiveness of Copper Carbonate Dust (50 per cent) in Prevention of Bunt of Different Physiologic Races
Season 1934

Physiologic races	Hybrid 128		Hohenheimer		Ridit	
	Check	Treated	Check	Treated	Check	Treated
T. tritici						
1[a]	65.0	2.1				
2	90.0	2.8				
7	61.0	4.0	9.5	1.3		
7a	81.5	7.8	58.0	2.4		
92a	83.0	2.1			26.1	0.0
117	86.5	2.0			3.3	0.0
T. levis						
22	65.0	0.3				
26	66.5	0.4				
32	90.5	3.8				
92	82.5	0.4			15.0	0.5

[a] Figures represent collection numbers.

of the other *T. tritici* races produced a greater degree of smutting in the untreated rows than 7 and 7a. On the other hand, 7a was less effectively controlled than 7 on both Hybrid 128 and Hohenheimer, a result which might be expected in view of the fact that 7a produced more smut on both of these varieties in the untreated rows than 7. This was true also with *T. levis,* in which number 32 produced the highest per cent of bunt on Hybrid 128 and was the least effectively controlled of all the *T. levis* races. The two *T. tritici* races and the one *T. levis* race on Ridit were equally well controlled.

On the basis of these results, therefore, there appears to be some evidence that the effectiveness of copper carbonate in the prevention of bunt may depend to some extent upon the physiologic races of *Tilletia tritici* or *T. levis* involved. However, in view of the fact that the results are for one year only and the differences in smut per cents relatively low it would be unwise to base definite conclusions upon them. More extensive trials are necessary in order to definitely determine whether bunt of some physiologic races is more difficult to control with copper carbonate than bunt of other physiologic races.

OTHER CONTROL PRACTICES

Effectiveness of Commercial Washing on Reduction of Bunt

Two different methods of removing smut from commercial wheat for milling purposes or for improvement of grade for resale have

been in use: (1) Scouring machines which remove the smut by abrasion; and (2) single or double cylinder washers which remove the smut by agitation while drenched with water (2). The question has been raised as to the application of these methods to cleaning wheat for seed. The scouring method has been shown to greatly reduce the per cent of germination and consequently, is not to be recommended for seed wheat. The washing process has, however, caused little if any reduction in viability (2). It would seem, therefore, that this method of cleaning might be of value in rendering very smutty lots of wheat available for seeding or at least much safer for seeding.

In order to test the effectiveness of the commercial washing process in reducing the per cent of bunt, samples of heavily smutted Triplet and Federation wheat, before and after passing through the commercial washer were obtained from the Federal Grain Supervisor in Portland for use in a field test. The results obtained in the spring of 1934 from rod-row plots replicated five times are presented in Table 9. On the basis of this performance it may be concluded that the washing removed smut as follows: Lot 1, 86, Lot 2, 81, Lot 3, 82, and Lot 4, 88 per cent. It is interesting to note that this is in close agreement with the per cent removal of 86.9 based on spore counts as reported by Bates et al. (2).

Reducing the spore load of heavily smutted seed has also been accomplished by mixing the seed grain in the drum of the dusting apparatus with sand or other abrasive, agitating for a time, after

Table 9. The Effectiveness of Commercial Washing of Seed Wheat on the Control of Bunt, Spring, 1934

Lot	Variety	Treatment	Per cent of smut heads 5 replications		
			Ave.	Max.	Min.
1	Triplet	Unwashed	24.5	28.5	21.0
	Triplet	Washed	3.5	5.7	1.6
2	Federation	Unwashed	12.5	13.4	10.1
	Federation	Washed	2.3	4.3	0.5
3	Federation	Unwashed	13.6	15.9	11.3
	Federation	Washed	2.5	3.4	2.3
4	Federation	Unwashed	25.6	30.8	19.2
	Federation	Washed	3.1	4.1	1.2
		Average for unwashed	19.1		
		Average for washed	2.9		

which the sand was removed (16) before treating with the dust fungicide. The effect of this method on germination was not reported. Good results of washing in water for the removal of bunt spores have been reported by Arnaud and Gaudineau (1) who have recommended this treatment as an adjunct to disinfectants. The reduction of the spore load of seed grain by one of these processes preceding the treatment with one of the standard dust disinfectants should make it possible to use heavily smutted seed for planting with a greater degree of safety. These results suggest that it may even be possible by improving the technique of cleaning so to reduce the spore load that the use of a seed disinfectant may not be necessary.

Surface vs. Trench Seeding

The seeding of cereals in trenched rows has been recommended as a desirable practice for the reduction of wind and water erosion and as a means of reducing winter killing. Several different companies have manufactured drills designed for trench seeding. This practice is adapted to level or gently rolling areas and with the orientation of the drill rows to run as nearly as possible at right angles to the direction of slope or the direction of the prevailing winds, run-off is retarded, snow is held and drifting of soil is materially lessened. This method of seeding has been briefly referred to as a cultural practice of value also in reducing the amount of wheat smut from soil contamination (10, 11) but the detailed results on which the recommendation was based have not previously been published.

The first results of trench seeding were obtained in periodic seedings of Hybrid 143 in the fall of 1918. Clean treated seed was planted on summer fallow exposed to natural contamination by wind-blown smut, one series of plots with normal surface seeding for contrast with an adjacent series in which the wheat was drilled at the bottom of trenches, about three inches deep. It was the belief that the throwing back of the surface soil would make it possible to have the soil at the bottom of the trench nearly free from wind-blown spores. The results of this test are presented in Table 10. The seeding with the regular drill gave results quite typical for periodic seeding when there is moderate soil contamination, with a maximum of 14.9 per cent of smutted heads on October 3. The maximum for trench-seeded plots was only 3.3 per cent of smutted heads, also on the same date.

A comparison of trench and surface seeding was made again in 1922 with three varieties of low, medium and high susceptibility planted at a date to give about maximum soil contamination. The results presented in Table 11 again show very marked reduction in the amount of smut as a result of trench seeding.

Table 10. Comparison of Trench Seeding and Regular Drill Seeding in Periodic Plantings of Clean Hybrid 143. Fall, 1918

Date of seeding	Per cent of smut heads	
	Regular drill	Trench seeded
8-15	0.0	0.0
8-22	0.2	0.5
8-29	0.0	0.0
9-6	1.4	0.9
9-12	0.1	0.0
9-19	2.5	0.2
9-26	5.3	2.0
10-3	14.9	3.3
10-10	8.9	2.4
10-17	4.2	3.3
10-26	6.6	0.0
11-2	0.0	0.0
11-7	0.0	0.0
11-14	0.0	0.0

Table 11. Comparison of Trench Seeding and Regular Drill Seeding on the Amount of Bunt

Fall, 1922

Treatment	Planting method	Per cent of smut heads		
		Hybrid 128	Red Russian	Turkey
None	Regular drill	17.4	9.8	1.5
Formaldehyde 1-40	Regular drill	18.6	5.7	0.6
Formaldehyde 1-40	Trench seeded	5.6	3.9	0.5

Similar tests were made in the fall of 1933 and 1934 using Hybrid 128, treated with formaldehyde to eliminate seed-born smut. A very low per cent of smut appeared during both seasons, indicating that the soil contamination was relatively light. Even under these conditions the amount of smut produced by trench-seeded plots was about half that of the surface-seeded plots (Table 12), the average for 50 rows of surface-seeding being 6.5 per cent smut as contrasted with 3.72 per cent for trench seeding in 1933 and 0.32 per cent as opposed

Table 12. Comparison of Trench and Surface Seeding on the Per Cent of Bunt from Soil Contamination

Hybrid 128

	Fall, 1933			Fall, 1934		
	Per cent of smut heads 10-Row-Plots			Per cent of smut heads 10-Row-Plots		
Surface seeded Plot number	Max.	Min.	Ave.	Max.	Min.	Ave.
1	10.8	0.8	6.08	1.3	0	0.1
2	11.0	2.3	6.40	1.4	0	0.4
3	8.8	3.0	6.10	1.4	0	0.4
4	10.1	1.3	5.70	2.0	0	0.5
5	10.9	4.8	8.10	1.2	0	0.2
Average	10.3	2.4	6.50	1.5	0	0.32
Trench seeded Plot number						
1	7.1	0.0	3.67	0.3	0	0.1
2	6.9	1.4	3.66	0.2	0	0.02
3	4.3	1.8	2.98	0.8	0	0.1
4	8.2	0.0	4.57	2.0	0	0.5
5	7.3	1.6	2.75	0.0	0	0.0
Average	6.8	1.0	3.72	0.7	0	0.18

to 0.18 per cent in 1934. On the basis of the several tests it would seem safe to assume that trench seeding may be expected to reduce the amount of smut to one half or even to two thirds that which will result from the ordinary type of seeding.

PHYSIOLOGIC STRAINS OF WHEAT VARIETIES

During the last few years much attention has been given to physiologic races of bunt, but little consideration to the possible relation of physiologic strains of wheat varieties to the incidence and severity of smut infection. It has previously been shown by Heald (10) that seed of the same variety from different sources when uniformly smutted and planted at the same time so as to give equal opportunity for infection, showed great variation in the per cent of smut in the crop. Turkey from seven different regions including Washington showed infection (*Tilletia tritici*) varying from 14.28 to 64.92 per cent of smutted plants.

The results obtained with Marquis seed from different regions when uniformly smutted and planted under exactly the same conditions at Pullman are presented in Table 13. The per cent of smutted

Table 13. Amount of Smut (*Tilletia tritici*) on Marquis Selections from Different States when Planted at Pullman. Spring 1919

Source of seed	Per cent of smut	
	Plants	Heads
Minnesota	42.55	14.64
North Dakota	28.49	23.83
Nebraska	25.00	14.75
Colorado	23.89	8.95
Montana	23.48	14.00
Oregon	27.39	26.84
Washington	18.39	3.73

Table 14. The Per Cent of Bunt Produced by Marquis from Different Locations when Inoculated with Different Physiologic Forms of *Tilletia tritici* and *T. levis* and Grown at Pullman

Source of seed 1933 crop	Tilletia tritici[a]			
	Test for 1934		Grown at Pullman 1934 Test for 1935	
	No. 2	No. 7a	No. 2	No. 7a
St. Paul, Minn.	61.6	61.6	43.0	7.4
Bozeman, Mont.	47.2	38.8	33.1	8.9
Tucson, Ariz.	22.7	29.4	36.7	10.2
Corvallis, Oregon	32.6	37.2	35.4	12.3
Moro, Oregon	45.5	47.3	38.0	11.4
Pendleton, Oregon	40.3	37.7	35.9	6.0
Pullman, Wn.	50.8	44.6	43.2	14.8
	Tilletia levis[a]			
	No. 18	No. 32	No. 18	No. 32
St. Paul, Minn.	87.3	61.1	29.4	44.0
Bozeman, Mont.	67.4	51.4	27.6	39.8
Tucson, Ariz.	63.0	26.2	29.6	25.2
Corvallis, Oregon	65.3	45.0	21.2	25.2
Moro, Oregon	77.0	56.6	30.3	37.7
Pendleton, Oregon	66.8	60.5	32.0	25.1
Pullman, Wn.	77.0	62.0	23.1	24.2

[a] The numbers used below indicate collections of the smut species.

plants varied from 18.39 in the Washington Marquis to a maximum of 42.55 in the Minnesota strain. The Washington Marquis with 3.73 per cent was the least smutted on the basis of the head count, while the Oregon selection with 26.84 per cent was the most affected.

More recently selections of Marquis from seven different stations have been tested for susceptibility to two races of *Tilletia tritici* and two races of *T. levis* (Table 14). The per cent of infection (smutted plants) with Collection No. 2 of *T. tritici* varied from a minimum of 22.7 in the Arizona selection to a maximum of 61.6 per cent in the Minnesota strain. The same strains were also low and high in susceptibility to Collection No. 7a of *T. tritici.* The variation in degree of smutting was less pronounced with the two forms of *T. levis,* and again the Minnesota selection was very susceptible, showing the highest per cent of smut with Collection No. 18 and next to the highest with Collection No. 32.

The Marquis selections from the seven different stations were grown at Pullman during the season of 1934 and their susceptibility tested again in 1935 to the same physiologic forms of *Tilletia tritici* and *T. levis* (Table 14). The results obtained indicate first that the conditions for infection were much less favorable, since the Pullman Marquis as well as all of the other selections showed much less smut than in 1934. The range between maximum and minimum was very greatly reduced for all of the four forms of smut employed (Table 15).

Another very noticeable feature was the disparity between the performance of Collection No. 7a (Table 14) and the other races, indicating that the seasonal conditions must have been much less favorable for infection by this race than for the others. In general, however, the results suggest that growth of different strains of Marquis in the same environment will tend to render them more uniformly susceptible to races of bunt.

The influence of a changed environment on the susceptibility of the Pullman strain of Marquis to the four races of bunt used in the

Table 15. Range between the Maximum and Minimum Per Cents of Bunt with the Seven Selections of Marquis

Species	Collection number	Test for 1934	Grown at Pullman 1934; test for 1935
T. tritici	2	43.9	10.1
T. tritici	7a	32.2	8.8
T. levis	18	24.3	10.8
T. levis	32	34.9	18.9

previous tests has been determined. Seed was sent to each of the stations listed, grown at those localities during the season of 1934, and then returned to Pullman for planting tests in the spring of 1935 (Table 16). It is significant that the varying degrees of smut obtained are quite comparable to the behavior of the various strains of Marquis when brought from distant stations to Pullman. The lots grown at Laramie, Wyoming and Logan, Utah in general showed the lower per cents of bunt, while the lot subjected to the conditions of the Fargo, North Dakota environment for one season produced the maximum amount of smut.

According to the results presented it is probable that the reaction of a variety of wheat or any strain of that variety to bunt is influenced by the environmental conditions to which it was exposed during the previous growing season.

Table 16. Per Cent of Bunt Produced by Marquis from Pullman Stock Grown One Year in Another Locality and Returned for Test

Planted Spring, 1935

Grown in 1934 at	Tilletia tritici[a]		Tilletia levis[a]	
	No. 2a	No. 7a	No. 18	No. 32
St. Paul, Minn.	28.6	27.6	24.6	25.0
Bozeman, Mont.	20.7	20.5	23.3	22.9
Laramie, Wy.	16.3	14.6	22.0	22.5
Fargo, N. D.	37.0	39.9	54.5	38.6
Logan, Utah	16.5	17.7	12.9	15.3
Pendleton, Oregon	35.7	12.6	19.0	34.5
Range between Max. and Minimum	20.5	27.3	41.6	23.3

[a] The numbers used below indicate collections of the smut species.

PHYSIOLOGIC RACES OF BUNT SPECIES

New Physiologic Races

Perhaps no other single factor has contributed more to the difficulty of bunt control than physiologic specialization in *Tilletia tritici* and *T. levis.* This phase of the bunt problem has been rather extensively investigated in recent years and in the United States alone about 30 forms of each species have been described by various investigators. Because of the lack of a standard system for identifying physiologic races it is undoubtedly true that some of the descriptions re-

Table 17. The Pathogenicity of Two New Races of *T. tritici* as Compared with Somewhat Similar Reces of *T. levis* and *T. tritici* Described by Others

Identification number	Species	Variety	Per cent smut	Author
Race 7	T. levis	Ridit	14.0	Gaines & Smith (7)
Race 3	T. levis	Ridit	26.6	Flor (5)
Collection 92a	T. tritici	Ridit	58.0	
Race 11	T. tritici	Hohenheimer	31.0	Gaines & Smith (7)
Race 7	T. tritici	Hohenheimer	22.2	Flor (5)
Collection 7a	T. tritici	Hohenheimer	77.0	

present duplicates. The fact remains, however, that there are numerous races of *T. tritici* and *T. levis* and experimental evidence seems to indicate that the number is continually increasing. This seems to be especially true in the Pacific Northwest where the number of races of *T. tritici* and *T. levis* now recognized is considerably larger than in 1928. At that time Gaines (6) described one race of *T. tritici* and two of *T. levis* occurring in eastern Washington and in this same area five years later Gaines and Smith (7) reported five races of *T. tritici* and two of *T. levis.* Flor (5) described seven races of *T. tritici* and six of *T. levis* which he identified from a large number of collections made in Washington, Oregon, and Idaho and stated that four of the races of each species had not been recognized in this area prior to 1931. Since that time three races of *T. tritici* which were not recognized by Gaines and Smith (7) and Flor (5) have been found in the state of Washington. The reaction of two of the new races of *T. tritici* on their differential varieties as compared with somewhat similar, but distinctly different races of *T. levis* and *T. tritici* described by the earlier workers (5, 6, 7) for the eastern Washington area is shown in Table 17. As indicated in Table 17 the race of *T. tritici,* Collection 92a, that smuts Ridit, is considerably more virulent than Race 7 of *T. levis* described by Gaines and Smith (7) and Race 3 of the same species described by Flor (5). Apparently then this is a new race of *T. tritici* in this area and is characterized by its high degree of virulence on Ridit. The other race, Collection number 7a of *T. tritici,* is distinquished by its high degree of virulence on Hohenheimer. In tests covering three years it has produced an average of 77 per cent bunt on Hohenheimer as compared with 22.2 per cent by Race 7 of the same species described by Flor (5) and 31 per cent by Race 11 as described by Gaines and Smith (7). The data in Table 17 indicate rather definitely that Collection 7a is a race of *T. tritici* which is distinct from those in this area described by others (5, 6, 7).

Criteria other than Pathogenicity

Difference in pathogenicity was the original basis for separating physiologic races of *Tilletia tritici* and *T. levis* and this method continues to be the primary basis for differentiating physiologic races of these organisms. However, several investigators have shown that characteristics of the spore balls, prominence of spore wall reticulations, and degree of stunting the host plant also serve as means for distinquishing between races. In one instance it has been shown that two races of *T. tritici* differ in at least seven ways (14) as follows: pathogenicity, spore ball characteristics, spore wall reticulations, size of the spores, length of the promycelia, relative stunting of the host, and nuclear behavior. Young (18) reported the appearance of a new race of *T. tritici* in Montana which could be distinguished from other races by spore size, prominent reticulations of the spore walls, the hard solid spore balls, poor spore germination, failure to obtain infection by seed inoculation and by excessive tillering and dwarfing of infected plants. A race of *T. tritici* similar to that described by Young (18) has been observed in Klickitat County, Washington for several years.[1] This race appears to be very conspicuous because of the degree of dwarfing and excessive tillering of infected plants, as shown in Figure 1. Because of the extreme dwarfing of the plants this smut has become recognized locally as the short smut and is prevalent in southern Idaho and northern Utah as well as in Montana and Washington. While it apparently has been present in these areas for several years there appears to be no direct indication that this short smut is spreading generally to other wheat areas of the Pacific Northwest. However, it is well established in those areas where it has been found and appears to be more difficult to control than other races of *T. tritici* and *T. levis*. Its characteristics as described by Young (18), with one exception, apparently are constant in other areas. He found the smut balls to be extremely hard and not powdery inside. The smut balls of the short smut in Washington, Idaho, and Utah are small and rounded, as shown in Figure 2, and extremely hard, but when crushed the spore mass is distinctly dry and powdery indicating that there may be a lower oil content in the spores of this race than of certain other races of *T. tritici*. The pathogenic reaction of this race on the standard set of host differentials has not been determined, because the usual method of seed inoculation does not produce infection. Furthermore, all attempts to germinate the spores of this race of *T. tritici* under laboratory conditions have been unsuccessful. In all these respects the short smut race of *T. tritici* in Klickitat County is similar to the short smut in Montana, Idaho, and Utah and apparently has not previously been reported in the state of Washing-

[1] Reports and specimens received from Roderick Sprague, Assistant Pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture.

Fig. 1. Turkey wheat showing from left to right: a normal smut-free plant; one affected with a race of *Tilletia tritici* causing extreme dwarfing; and the third affected with a race of *Tilletia levis*.

ton. Therefore, in the wheat regions of the state of Washington we now recognize at least three races of *T. tritici* which were not described by earlier workers. As already pointed out, these races are easily distinguished from previously described races and at least two of them, the Ridit and Hohenheimer races, appear to be new races in this region. Therefore, the number of physiologic races in this area is considerably larger than it originally was and this fact has given rise to the question as to how new races of bunt originate.

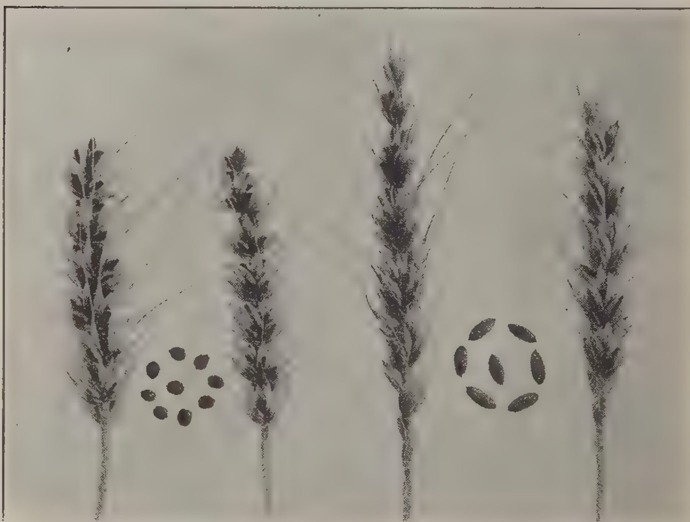

Fig. 2. Turkey wheat showing from left to right: smut balls and two heads from a plant affected with the race of *Tilletia tritici* causing extreme dwarfing; and smut balls and two heads from plants affected with an accompanying race of *Tilletia levis*.

Origin and Increase of Physiologic Races

It is generally recognized that new races of *Tilletia tritici* or *T. levis* may be the result of mutation or of hybridization between species or existing races within the two species. The fact that *T. tritici* and *T. levis* do hybridize has been demonstrated by Flor (4) and Hanna (8) but there seems to be no experimental proof that new races arise through the natural processes of hybridization and mutation. Theoretically, however, the possibility can hardly be disputed. Therefore, any one collection of *T. tritici* or *T. levis* may be a hybrid

and possess the potentialities for producing one or more new races. Furthermore, a population of these species in any given area may harbor physiologic races which do not express themselves because of the absence of the proper host varieties. It appears to be significant that the introduction of smut-resistant varieties into a number of given areas has been followed by the appearance in those areas of previously unrecognized races of bunt. For example, the durum wheats of the hard-red-spring-wheat region were highly resistant to bunt for many years prior to 1935 but within two or three years following that time bunt became an acute problem in these wheats. At about the same time growers of the bunt-resistant Marquis began complaining about smut in that variety. The results of investigations showed definitely that the durum bunt was caused by a previously undescribed physiologic race of *T. tritici* (12) and the Marquis bunt by a new race of *T. levis* (13). Furthermore, the distribution of these two races of bunt paralleled that of the durum wheats and Marquis, respectively. Gaines (6) reported similar experiences in connection with Turkey, C. I. 6175, and Kharkof, C. I. 1442. Flor (5) found four physiologic races each of *T. tritici* and *T. levis* in the Pacific northwest that had not been recognized in that region prior to 1931, and states that these new races were especially prevalent in the regions where the resistant varieties Ridit and Albit were grown. Experiences of this type would seem to indicate that the growing of resistant varieties tends to promote the increase and spread of new races of bunt. Undoubtedly this is due, at least in part, to the practice of omitting seed treatment where smut-resistant varieties are grown. The advisability of this practice is questionable, because of the fact that, while certain wheat varieties are resistant to bunt, they are nevertheless vulnerable to attack, even though the percentage of smut produced usually is very low. In cases of this kind the omission of seed-treatment for succeeding crops allows the slight amount of inoculum to gradually increase and in the course of a few years a variety which previously had appeared to be highly resistant may show high susceptibility because of an increase in the inoculum of one or more races of *T. tritici* or *T. levis* that are especially virulent on that variety. This increase in the inoculum may be the result of the screening out of already existing races from heterogeneous collections or from the propagation of new races that probably are constantly arising through natural processes.

VARIETAL RESISTANCE

It is generally recognized that successful control of bunt involves the growing of resistant varieties and the proper application of approved methods of seed treatment and cultural practices. However, the various methods of seed treatment frequently are applicable only

Table 18. Showing the Susceptibility of Certain Standard and New Varieties of Wheat to the Bunt Prevalent in Pullman, Wn., and in Pendleton, Oregon

Variety	C.I. No.	Station	Per cents of smut[c]				
			1932	1933	1934	1935	Ave.
Hymar	11605	Pullman			87.5	74.2	80.8
Hymar	11605	Pendleton			4.8	0.6	2.7
Albit	8275	Pullman	86.0	84.0	87.5	53.5	77.7
Albit	8275	Pendleton	3.4	34.2	10.9	1.2	12.4
Ridit	6703	Pullman	2.6	39.5	13.3	10.7	16.5
Ridit	6703	Pendleton	9.7	0.5	4.1	6.0	5.0
Oro	8220	Pullman	4.4	3.5	0.4	2.5	2.7
Oro	8220	Pendleton	9.7	0.6	0.6	1.4	3.0
Rex	10065	Pullman	69.1	82.5	77.5	46.2	68.8
Rex	10065	Pendleton	9.5	23.5	4.0	2.0	9.7
Hybrid 128	4512	Pullman	88.0	81.4[a]	90.0	87.2	86.6
Hybrid 128	4512	Pendleton	92.5	70.5[b]	96.0	97.0	89.0

[a] Per cent of smut for Kharkof.
[b] Per cent of smut for Minhardi.
[c] Data obtained from mimeographed report on Cooperative Uniform Smut Nurseries at Pullman, Washington and Pendleton, Oregon.

to certain areas and the methods must be varied according to the peculiarities of the locality. Similarly, from the standpoint of smut resistance, a variety may be adapted to one locality and not to another. A difference in the reaction of a variety of wheat to bunt in two different areas usually is attributed to a difference in the prevalence of physiologic races of *Tilletia tritici* and *T. levis*. On the other hand this difference may be due to the influence of environmental factors (17). Therefore, in order to determine the adaptability of wheat varieties to various localities, with regard to bunt resistance, it is necessary to make tests in each locality with local races of *T. tritici* and *T. levis* rather than at one station with a composite of races from several different areas.

During the four-year period from 1932-35 experiments were conducted to determine the resistance to bunt of a number of standard commercial winter wheat varieties and certain new varieties. These tests were made at Pullman, Washington, and Pendleton, Oregon. The inoculum for each of the two tests was obtained each year, by collecting smutted heads from commercial wheat fields in the area and making a composite of the collections. About 0.5 gram of spores was added to 100 grams of seed and the mixture agitated in a coin envelope so as to thoroughly coat each kernel. Each variety was grown in duplicate eight-foot rows and the percentage of smut was determined on the basis of total heads per row. The summarized results in Table 18 indicate that the new variety Hymar was highly susceptible to the races of *Tilletia tritici* and *T. levis* that were prevalent in 1933 and 1934 in the Pullman, Washington area and highly resistant to the prevalent races in the Pendleton, Oregon area. Likewise Albit was highly susceptible at Pullman and relatively resistant at Pendleton, although at Pendleton in 1933 there was 34.2 per cent bunt in this variety. Ridit was somewhat resistant at both stations, but in 1933 at Pullman 39.5 per cent bunt was produced on this variety. This would seem to indicate rather definitely that the inoculum for that year was composed primarily of Ridit races. The average on Ridit for the four years at Pullman was 16.5 per cent as compared with 5.0 per cent at Pendleton. Oro was highly resistant to bunt at both stations, with a four-year average of 2.5 and 3.0 per cent at Pullman and Pendleton respectively. Rex, a variety that has recently been distributed in parts of Oregon, was susceptible to bunt at Pullman with a four-year average of 68.8 per cent as compared with a 9.7 average at Pendleton.

These results are clearly indicative of a difference in the prevailing physiologic races of *Tilletia tritici* and *T. levis* in the two regions. Ridit and Albit, varieties widely grown in the Pullman area, in general, were more susceptible to the bunt in that area than at Pendleton. The variation from one year to another in the susceptibility of Ridit

Table 19. The Reaction of Winter Wheat Varieties to Individual Races and Composites of Physiological Races of *Tilletia tritici* and *T. levis* Planted Fall, 1934

Smut races[a] and the per cents of smut with the several varieties							
Smut race[a] or mixture	Hohenheimer	Smut race[a] or mixture	Martin	Smut race[a] or mixture	Oro	Smut race[a] or mixture	Ridit
1	0.5	1	0.7	1	1.9	1	2.4
5	0.0	2	49.1	5	0.4	5	2.2
6	0.0	5	0.4	6	0.8	6	1.4
7a	52.6	6	0.2	13	2.3	7	0.6
13	36.1	13	1.4	32	61.7	92a	50.3
19	0.0	19	1.4	17	2.2	7a	1.0
20	0.0	20	0.0	18	3.0	8	0.6
21	0.0	21	0.5	19	2.8	9	0.4
23	0.0	23	0.0	20	0.0	10	2.8
24	0.0	24	2.0	21	7.2	13	3.2
26	0.0	26	0.0	24	3.1	16	6.5
28	0.0	29	1.3	26	4.1	17	2.2
29	0.4	32	0.5	29	6.6	18	3.0
30	0.0	35	0.7	30	4.9	19	3.0
31	0.0	36	0.8	31	6.8	20	2.4
33	0.0	16	39.2	33	5.3	21	3.8
34	0.0	191	0.7	34	3.4	22	3.9
71	0.0	192	1.2	71	4.8	23	7.2
73	0.0	193	0.8	73	4.2	24	1.8
78	0.0	194	33.0	78	2.0	26	9.3
First 5	13.7	First 5	23.8	First 5	38.6	First 5	24.5
First 10	5.1	First 10	13.4	First 10	28.9	First 10	13.5
First 15	4.8	First 15	7.8	First 15	24.8	First 15	11.8
All 20	3.2	All 20	12.2	All 20	17.9	All 20	9.1

[a] Smut races are referred to by Collection Numbers.

at Pullman and Albit at Pendleton is assumed to be due to differences in physiologic races, inasmuch as the conditions were favorable for infection each year, as indicated by the high percentages of bunt on the susceptible variety, Hybrid 128.

At this point it may be well to consider to what extent the method of using composite samples of races of *Tilletia tritici* and *T. levis* can be relied upon in varietal resistance tests. The effectiveness of the commonly accepted practice of inoculating seed of varieties to be tested with composite samples of physiologic races has its limitations, depending upon the number of races involved in the composite, as shown by the results of an experiment summarized in Table 19. Each variety was inoculated with 20 physiologic races of *T. tritici* and *T. levis* individually and in composites of 5, 10, 15 and 20 races as indicated in Table 19. The composites were thoroughly mixed and consisted of equal amounts by weight of each race. The seed was inoculated in the usual manner and planted in eight-foot rows replicated four times. Each composite included one or more races to which the variety was susceptible.

Hohenheimer inoculated with collections 7a and 13 showed 52.6 and 36.1 per cent bunt, respectively, but was highly resistant to the other 18 physiologic races. The composite of 5, 10, 15, and 20 races produced 13.7, 5.1, 4.8, and 3.2 per cent, respectively on this variety. Collection 2 on Martin produced 49.1 per cent bunt while the composites of 5, 10, and 20 races produced 23.8, 13.4, 7.8, and 12.2 per cent respectively. The higher percentage of smut produced by the composite of 20 races than by the composite of 15 is due to the fact that Martin was susceptible to two of the last group of five races. Oro and Ridit also showed the same general trend, from high percentages of bunt produced by certain individual races and relatively low percentages by the composites. Therefore, it becomes apparent that the use of composites of a large number of races of *Tilletia tritici* and *T. levis* is not a reliable means of determining the absolute bunt-resistance of varieties. On the other hand, it usually is not feasible, or even necessary, to make individual race tests. It would seem that sufficiently reliable data can be obtained by using for inoculum a composite of no more than eight or ten physiologic races. However, if 15 or more races were included in a composite mixture to be used for varietal resistance tests the inoculum of any one race to which a variety is susceptible would not be sufficiently concentrated to produce a high degree of infection. In such a case there would be a probability that the data might lead to an incorrect conclusion as to the resistance of the varieties tested. In other words a variety might show resistance to the composite of races and be highly susceptible to only one of these. If the race to which a variety is susceptible is prevalent in the area where the variety is to be grown it follows that it would

be unwise, from the standpoint of bunt resistance, to distribute the variety in that area, regardless of its resistance to other races of *T. tritici* and *T. levis*.

EFFECT OF BUNT ON THE WINTER HARDINESS OF CERTAIN VARIETIES OF WHEAT

Following the severe winter of 1931-32 observations were made in the wheat smut nursery at Pullman which indicated that smutted plants of certain varieties were more susceptible to winter injury than smut-free plants. To obtain more definite data on the behavior indicated by these observations, tests were made in 1932-33 to determine the effect of infection with Tilletia on the winter hardiness of certain varieties of wheat.

Six varieties of wheat, ranging in smut reaction from highly susceptible to highly resistant, were used in this experiment. The seed of each variety was divided into four equal quantities and each smutted with a composite of physiologic races of *Tilletia tritici* and *T. levis* as follows: Lot 1 at the rate of 0.1 gram inoculum to 100 grams of seed; lot 2 at the rate of 0.5 gram to 100 grams; lot 3 at the rate of 1.0 gram to 100 grams; and lot 4 was left uninoculated for a control. A supplementary test was made with Ridit, using the Ridit race of *T. tritici,* to determine whether this variety would exhibit a differential reaction to winter injury when inoculated with this race as compared with its reaction in the inoculations with a composite of races to which it is resistant.

The seed was space-planted in rod-rows, 75 kernels to the row, and there were four replications of each test. Following germination and emergence the seedlings were counted and the number in each row was recorded and used as a 100 per cent basis for computing the per cents of survivals at maturity. There were slight variations in the number of seedlings in different rows. However, there was no indication that the smut had any appreciable effect upon seedling emergence. The per cent of plants that survived and the per cent of smut in each row was determined at harvest time and the averages of the four replications are presented in Table 20.

The data obtained indicate a rather pronounced effect of the smut on winter hardiness of certain varieties. For example 90.5 per cent of the plants of Hybrid 128 in the non-smutted rows survived the winter as compared with 58.0 per cent of survivals in the most heavily smutted rows. Federation, a fall-sown spring wheat, had a very low per cent of survivals in all the rows but the per cents in the smutted rows were lower than in the non-smutted rows. In Minhardi and Albit the percentages of survivals in the rows with light smutting were about the same as in the non-smutted rows. However, the

Table 20. The Effect of Infection with Tilletia on the Winter Hardiness of Wheat Varieties[a]

Variety	C.I. No.	Grams of inoculum to 100 grams of seed							
		0.0	0.1	0.5	1.0	0.0	0.1	0.5	1.0
		Per cent stand at maturity				Per cent smut			
Hybrid 128	4512	90.5	74.7	74.7	58.0	1.7	81.5	75.5	78.5
Federation	4734	24.2	22.0	16.2	7.0	2.2	51.5	62.6	78.0
Minhardi	5149	95.2	93.5	89.5	70.7	3.4	50.0	66.5	68.0
Albit	8275	90.5	90.5	89.5	82.7	0.9	27.2	54.2	61.2
Jenkin x Ridit	10081	97.7	91.2	93.2	88.0	0.0	1.3	2.7	4.2
Ridit	6703	86.5	86.0	73.5	79.0	0.0	4.0	8.2	9.2
Ridit[b]	6703	92.2	93.2	90.5	87.0	0.0	32.2	41.5	48.7

[a] Data from plantings made by the senior author in cooperation with A. M. Schlehuber, Research Fellow in Agronomy.

[b] Inoculated with the Ridit race of *Tilletia tritici*.

heavily smutted rows had notably lower per cents of survivals than the other rows of these varieties. The highly resistant variety, Jenkin x Ridit, showed a slight but definite indication of decreased winter hardiness due to the effect of the smut. Similarly the winter hardiness of the resistant variety Ridit appeared to be appreciably reduced by the smut. It is notable also that the composite of races to which Ridit is resistant caused a slightly greater reduction in its winter hardiness than the race of *Tilletia tritici* to which this variety is susceptible. It is evident, therefore, that infection with *T. tritici* and *T. levis* renders plants of certain varieties of wheat more susceptible to winter injury than non-infected plants. The effect appears to be more pronounced in some varieties than in others and there are indications that its degree is dependent upon the normal winter vigor of the varieties. Consequently this factor should be taken into consideration in determining the smut-reaction and winter hardiness of wheat varieties. In other words, if the number of plants has been appreciably reduced by severe winter conditions the true smut reaction of a variety may not be obtained on the basis of the remaining plants because of the probability that the greater proportion of the plants which did not survive were infected and would have shown smut at maturity. Similarly an index to the winter hardiness of a variety may not be obtained from the tests involving smut reaction, because of the fact that at least part of the winter injury may be attributable to the effect of the smut. Undoubtedly, therefore, the winter hardiness and smut reaction of wheat varieties would be more accurately determined by independent tests.

From the commercial point of view it obviously is fortunate that plants which are infected with the smut fungus are less winter hardy than non-infected plants. A wheat plant which is destined to produce smut instead of wheat is a potential loss in yield and if allowed to mature it produces further losses by reducing the market value of the threshed grain and supplying inoculum for smut production in future crops.

SUMMARY

1. Copper arsenite dust was no more effective than copper carbonate dust in the prevention of bunt from soil contamination.

2. Basic copper sulphate dust not only caused no seed injury to treated seed held for one year, but resulted in an improved germination over untreated seed. This dust gave complete control of bunt when used with moderately smutty seed and only traces of bunt with heavily smutted seed in spring seedings of Federation and Marquis. Holding seed for one year after treating with basic copper sulphate did not lessen the effectiveness of this dust.

3. Holding seed treated with copper carbonate for periods ranging from three weeks to nine months previous to planting did not materially affect the efficiency of the control in spring plantings of Federation, but did lessen the protective value of Ceresan. Fall seedings with Hybrid 128 held for three weeks to three months previous to planting were about equally protected, but good control was not obtained possibly because of soil contamination and other complicating factors. Periodic seedings of heavily smutted Hybrid 128 showed a decreasing effectiveness of the treatments from early September to late October seedings.

4. New Improved Ceresan at one-half ounce per bushel gave as good control as Ceresan at two ounces per bushel.

5. Data obtained with different physiologic races of bunt indicate that copper carbonate does not always give equal protection. Poorer control was obtained when races of *Tilletia tritici* were used than when races of *T. levis* were employed.

6. Commercial washing of smutted wheat for milling purposes offers some promise as a method of cleaning wheat for seeding, since 80 per cent or more of the smut spores may be removed. This process would make it possible to clean heavily smutted grain for seed and use one of the standard dust disinfectants with reasonable safety.

7. Trench seeding as compared with normal drill seeding has given less smut in periodic plantings under natural field conditions and in artificially contaminated soil has reduced the per cent of smut by at least one half.

8. Marquis wheat obtained from different regions and uniformly smutted and planted at Pullman gave varying amounts of smut. The variation was greater with *Tilletia tritici* than with *T. levis*. Growing the strains for one year at Pullman made them somewhat more uniformly susceptible, while Pullman seed grown one year in other localities and returned to Pullman for seeding showed variations in the percentages of smut produced ranging from 12.6 to 39.9 for *Tilletia tritici* and 12.9 to 38.6 for *T. levis*.

9. Two new physiologic races of *Tilletia tritici* for Washington have been added to the list previously recognized, one which attacks Ridit rather severely, while the other shows a high degree of virulence on Hohenheimer.

10. The separation of physiologic races by criteria other than pathogenicity is discussed and a new race of *Tilletia tritici* is described which is distinguished from others by spore size, prominent reticulations of the spore walls, the hard spore balls, poor spore germination, failure to obtain infection by planting smutted seed and by excessive tillering and dwarfing of infected plants.

11. Data are presented which suggest that the growing of resistant varieties of wheat has tended to promote the increase and spread of new races of *Tilletia tritici* and *T. levis* which may have arisen by hybridization of species or races or by mutation.

12. Tests on varietal resistance have shown that results obtained in different regions may be different owing to the prevalence of different races of bunt. It is also shown that the use of composites of a large number of races of *Tilletia tritici* and *T. levis* is not a reliable method of determining the absolute bunt resistance of varieties.

13. Winter killing of wheat is affected by the degree of infection with bunt, the losses in general increasing with increase of spore load carried by the seed. Consequently indices of real winter hardiness can not be obtained from heavily smutted plantings, while plantings showing winter injury are not reliable for determination of smut resistance.

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